

**A Review of the Characteristics and Fate of Suspended Solids
Discharged with Biologically Treated Effluents from Pulp and Paper Mills**

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Introduction

Wastewater treatment plants with even the best design and operation discharge some suspended solids in the treated effluent. Once these solids enter a receiving water there are several possibilities regarding their behavior and fate. They may, in whole or in part: remain suspended, become dissolved, settle out, become re-suspended, associate with other suspended matter, or become part of the food chain. Fate is influenced by characteristics of the solids, such as particle size, density, and chemical composition.

Questions and assertions are raised periodically by regulatory agencies and others regarding the fate of suspended solids discharged from wastewater treatment plants. In the 1970s, as one example, the Corps of Engineers claimed that suspended solids released by biological treatment plants behaved in the same manner as sediment from land erosion, and thus point dischargers should bear some of the costs of dredging projects (NCASI 1978c; NCASI 1978d).

This report summarizes readily available information on the characteristics and fate of suspended solids discharged with biologically treated effluents from pulp and paper mills. Biological treatment, generally either by activated sludge plants or aerated stabilization basins (ASBs), is standard practice for paper industry wastewater that is to be discharged to surface water. An overall summary of the findings is presented below, followed by more detailed summaries of individual references.

Executive Summary

In general, suspended solids in biologically treated effluents from pulp and paper mills are mostly biological in origin, consisting of bacteria and bacterial cell fragments, and small amounts of mineral matter. The solids are of very small particle size, typically less than 10 μm in diameter. This small size contributes to the difficulty in settling the solids in a treatment plant and constrains settling in receiving waters. The nitrogen and phosphorus contents of the solids are on the low end of the levels found in bacteria.

Information from laboratory, artificial-stream, and field studies, as well as empirical evidence, strongly indicates that suspended solids in mill effluents do not easily settle in receiving waters, are easily re-suspended if they do settle, and do not accumulate to a noticeable degree on the beds of receiving waters. As they are largely organic in composition, the solids serve as food for aquatic organisms and thus are incorporated into the tissues of the organisms.

Characteristics of Suspended Solids in Biologically Treated Pulp and Paper Mill Effluents

Characteristics of suspended solids in treated effluents from three pulp and paper mills as well as a pilot unit treating diluted kraft black liquor have been described (NCASI 1978a). Two of the mills were integrated bleach kraft operations utilizing activated sludge treatment with long hydraulic retention times (HRTs) in the aeration units, namely 3.5 and 10 days. Clarifier HRTs were 2.7 hours at one mill and 7.0 hours at the other. Coagulant was added to the secondary clarifiers at each mill (alum in one case and alum plus polymer at the other). The third mill produced paperboard from recovered paper and had a 10-day HRT ASB and settling ponds with an HRT of 2.5 days. The pilot ASB treating diluted black liquor had an aeration HRT of 5 days and two sedimentation units with a combined HRT of 10 days. Suspended solids in all final effluent samples examined were not reported, but for those that were, they varied from 20 mg/L to more than 100 mg/L.

Suspended solids characterization was mostly directed at the determination of particle size using scanning electron and optical microscopy with “sieve analysis,” i.e., fractionation with membranes (NCASI 1978a). Solids were also characterized by Zeta potential measurements, qualitative elemental analysis, and determination of deoxyribonucleic acid (DNA) content. It was concluded that solids discharged from secondary treatment facilities were primarily organic and compressible in nature and were generated during biological treatment. The solids were generally less than 8 μm in size¹. Viability of this material determined by DNA analysis was found to be less than 25 % by weight, the remainder consisting of non-living cell fragments and inorganic matter. The dispersed form of the solids were likely due to steric hindrance and/or adsorption of hydrated hydrophilic colloids rather than charge repulsion, which would explain the difficulty encountered in coagulating the particles at reasonable chemical doses.

The suspended solids from a laboratory biological reactor and in the discharge of a mill ASB treating the same bleached kraft mill effluent were analyzed using a phase microscope and a hemacytometer (NCASI 1978c). A hemacytometer is a ruled and calibrated glass slide for counting cells. The findings indicated that the suspended solids from both sources were almost entirely biological in origin, being either individual or flocculated bacteria. The bacteria comprised over 95 percent of the suspended solids when either number or volume was considered. It was estimated that seventy-five percent or more of the particles were less than 1.5 μm in size and nearly all were 10 μm or less in size. Overall, the two effluents exhibited many similarities such as the abundance of small particles, small flocs, and rod shaped bacteria single or in pairs, and some filamentous bacteria.

Biskner, Millican, and Barton (1976) provided information on the particle size of suspended solids present in the effluent discharged from two mills. One mill engaged in sulfite pulping and treated its wastewater with an activated sludge system, and the other produced bleached kraft pulp and had an ASB for wastewater treatment. In both cases, a large majority of the suspended

¹ As bacteria of spherical and rod-like shape typically vary from 0.3 to 10 μm in size (Metcalf and Eddy 2003), the information presented in this report suggests that the solids are of a size expected for single bacteria or for flocs of a few bacteria.

solids in the final effluents were less than 5 μm in size with few if any particles large than 20 μm . The small particle sizes made granular, mixed-media filtration ineffective in significantly reducing the level of suspended solids in the effluents.

The Academy of Natural Sciences of Philadelphia studied the suspended solids in treated effluent from an integrated sulfite pulp mill with an activated sludge plant, including an examination of particle size (ANSP 1977). The solids were found to be principally within the narrow size range of 0.83 to 1.4 μm , with some larger particulate matter also present.

The particle size distributions in activated sludge effluents from two mills in Finland have been presented by Kasko (1996). One of the mills produced kraft pulp, and the other was a nonintegrated paper mill. Particle size was measured using a laser diffractometer. Most of the suspended solids were smaller than 1.5 μm in the paper mill effluent and less than 0.5 μm in the pulp mill effluent, but some particles were greater than 50 μm in size.

Levels of settleable solids in treated mill effluents have been reported by NCASI (1986). Settleable solids were measured using the standard laboratory procedure involving an Imhoff cone and a quiescent settling period of 60 minutes. The study was conducted in light of the possibility that state regulatory agencies might place limits on discharged settleable solids in NPDES permits, rather than evaluating the procedure as a simulation of solids behavior in receiving waters. Sixteen mills representing eleven categories of pulp and paper production participated in the twelve month study to characterize the settleable portion of the total suspended solids in treated discharges. Thirteen of the mills provided some form of biological treatment while the remaining three facilities practiced chemically assisted clarification. Collectively, the volumetric settleable solids measured during the study were 3.0 ml/L, 15.5 ml/L, and 26 ml/L (0.3%, 1.55%, and 2.6% by volume) respectively for long-term average, maximum monthly, and maximum daily performance periods. The level of settleable solids in treated effluent did not appear to be function of the type of treatment. On a mass basis, settleable solids obtained from the laboratory procedure typically represented 40% to 60% of the total suspended solids.

In conducting research to quantify the rates and extents to which organic nitrogen and phosphorous in biologically treated mill effluents degrade to bioavailable inorganic forms, NCASI developed data on suspended solids concentrations in discharged effluents as well as other information that allow for some chemical characterization of the suspended solids (NCASI 2004, 2009). In particular, the volatile and nutrient contents (phosphorus and nitrogen) of the solids can be estimated. Data were obtained from ten mills representing several types of production, and they encompassed both of the major types of biological treatment in the industry - activated sludge systems and aerated stabilization basins. The average levels of suspended solids among individual mills ranged from approximately 10 mg/L to 80 mg/L with a collective average for the mills of 30 mg/L. Average volatile contents of the suspended solids among individual mills ranged from 56% to 87% with a collective average of 74%. Similarly, the phosphorus content of the solids varied from 0.5% to 1.9% with a collective average of 1.1%. For nitrogen, the values ranged from 2.4% to 18% with a collective average of 7.8%. The nutrient contents are on the low end for the levels found in bacteria (Egli 2000).

Behavior and Fate of Suspended Solids in Biologically Treated Pulp and Paper Mill Effluents

The Academy of Natural Sciences conducted preliminary work on the effects of suspended solids in biologically treated wastewaters from facilities in the Northeast (ANSP 1977). The work was performed mostly with effluent solids from an integrated sulfite pulp mill having activated sludge treatment, but solids from a municipal treatment plant and from a chemical plant were also investigated. The findings were as follows: (a) the suspended solids were not at a concentration high enough to interfere with photosynthesis in a stream, (b) nutrients associated with the solids stimulated the growth of the algae *Scenedesmus abundans* but with no deleterious effect found, (c) bacterial cells in the effluent did increase in number upon entering stream water but the increase was not substantial and was limited by the nutrient content of the stream water, and (d) the suspended solids proved to be a satisfactory food for protozoa.

NCASI (1978c) described an investigation into the fate of biological solids from the treatment of kraft mill effluent in warm-water artificial streams. Artificial streams provide controlled conditions that are very close to conditions existing in nature, and they offer easy accessibility for timely sampling and study. Suspended solids used in this work were C-14 labeled and generated in a laboratory biological reactor simulating an ASB (no sludge recycle) receiving whole-mill effluent from a bleached kraft pulp mill. The solids were introduced to artificial streams having pool and riffle areas and to which water from the Neuse River in North Carolina was already being fed. The in-stream concentration of suspended solids from the solids introduction was between 1 and 2 mg/L. The streams previously were stocked with several types of organisms such as caddis flies, snails, amphipods, leeches, and beetle larvae, after periphyton had been established. It was found that some solids were ingested by a variety of invertebrates including both grazing and filter feeding organisms, and were incorporated into their tissues. In turn, consumption of the invertebrates by fish occurred with a demonstration that C-14 was incorporated into fish tissue. A comparison of the amount of organic benthic matter accumulated in the pools of control streams and those receiving the effluent suspended solids for a period of more than two years showed no measurable difference.

The findings were reported for a study in which effluent from an unbleached kraft linerboard mill was introduced into cold-water artificial streams containing many pools and riffles (NCASI 1977). The streams, including control streams receiving no effluent, utilized water from the Willamette River in Oregon. One of the objectives of the study was to evaluate the impact of suspended solids in the ASB treated effluent on the benthic community. No measurable changes in benthic organisms, including filter feeding organisms, indicated that an incremental increase of 2 to 3 mg/L of suspended solids from biologically treated mill effluent had no detrimental effects on benthic populations.

NCASI (1978b) investigated at three sites the extent of deposition of solids discharged with treated mill effluent via diffusers into relatively quiescent areas of receiving streams. Effluent at each site had undergone biological treatment and secondary clarification before discharge. At each of sites, several sample locations downstream but near the outfall were examined as was an upstream location. Sensory observations were made by divers, core samples were taken, and

sediment traps were installed for the accumulation of deposition over a one year period. These examinations of benthic conditions revealed no sludge layers, and no evidence of a definitive impact from effluent solids was found.

NCASI (1978d) conducted a field study on the fate of suspended solids discharged from the treatment plant at a mill in New York State producing boxboard from wastepaper. Features of the treatment plant included an aerated stabilization basin with a 10-day hydraulic retention time followed by two settling ponds with a combined retention time of 2.75 days. The final effluent had a flow rate and suspended solids concentration ranging from 0.5 to 1.0 MGD and 10 to 20 mg/L, respectively. With a dilution factor at the point of discharge of 6:1, the in-stream concentration of suspended solids was initially about 2 mg/L. Carbon-14 labeling of the suspended solids provided a means of tracking the fate of the solids in the river system. The river reach studied had a length of 10 miles and a time of travel of 7 days, and it offered conditions consisting of intermittent riffle and free flowing areas interspersed with impoundments. The investigators determined that over 96% of the discharged solids either remained suspended or were metabolized, even with velocities an order of magnitude lower than normally associated with scouring of organic particles. Sediment traps placed in pools behind dams, where earlier work found no discernible bottom deposits of mill solids, captured less than 4% of the material. It was also determined that mill solids were ingested by a variety of invertebrates including both grazing and filter feeding organisms.

Velinsky et al. (2003) employed the isotopic signature (C-13 and N-15) of solids ($> 0.7 \mu\text{m}$) in a biologically-treated discharge from a pulp mill on the Jackson River in Virginia to determine the influence of the solids on isotopic compositions of material transported downstream and the potential incorporation of the solids into benthic algae, macroinvertebrates, and fish. Effluent solids consisted predominantly of biological material, and had unique and easily traceable isotopic markers. Suspended effluent solids decreased substantially by 19 miles downstream of the mill, and this information combined with the biological data suggested that solids were a source of food and were integrated into the food chain.

The Water Research Laboratory (WRL) at the University of New South Wales recently completed a project that investigated the physical properties of suspended solids expected to be present in the effluent discharged from a pulp mill proposed for Bell Bay in Australia (www.wrl.unsw.edu.au/site/projects/effluent-particle-dynamics-gunns-pulp-mill). Effluent is to be treated with an activated sludge system before discharge into Bass Strait via a diffuser three miles from the coast. The study was designed to simulate with laboratory physical models the movement of suspended solids during their transport in the discharge pipe and in the marine environment within the near-field zone, including settling and re-suspension dynamics. The work was conducted at the Veracel pulp mill in Brazil, which was identified as producing an effluent equivalent to the one expected at the proposed mill. The researchers studied floc size evolution, settling rates of flocculated material, critical shear velocity for floc re-suspension, and partitioning studies of flocs under various mixing levels. WRL also collaborated with a consulting firm to develop a dynamic sediment transport model for assessing particle transport and concentrations within the near-field. The results indicated that suspended solids discharged from the proposed outfall were unlikely to settle in the near-field zone of the outfall. Further,

any solids that might settle would be quickly re-suspended and transported away from the site. Note that this research examined physicochemical behavior only, ignoring the effects of fauna on the fate of the solids².

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² The description of the WRL research is based on the limited information provided at the WRL website. Although the website for the planned Bell Bay Pulp Mill contains numerous documents, a report on the WRL research did not appear to be available, possibly because the project was recently completed. The website does have a document about the scope of hydrodynamic modeling and field measurements to be conducted for the proposed outfall ([www.gunnspulpmill.com.au/permits/epbc/L/Appendix D - Hydrodynamic Modelling and Measurement Scope and Plan.pdf](http://www.gunnspulpmill.com.au/permits/epbc/L/Appendix%20D%20-%20Hydrodynamic%20Modelling%20and%20Measurement%20Scope%20and%20Plan.pdf)).

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